

One-to-one mobile technology in high school physics classrooms: Understanding its use and outcome

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Abstract

This study examined ways in which high school students used mobile devices in physics classrooms and after school, and the impact of in-class and after-school mobile technology use on their physics learning performance and interest. We collected data from 803 high school freshmen in China after they had used mobile devices for over five months. A fixed-effects model was employed to control the undetected variances. Results indicated that the students frequently used their mobile devices for physics learning in class and after school. Students also perceived the mobile devices as very useful for their physics learning, and their perception of usefulness was positively correlated with their frequency of use. Both the in-class and after-school duration and frequency of mobile technology use positively influenced students' physics learning achievement and interest. However, we also found that mobile technology was mainly used to augment rather than to transform instructional practices in physics classrooms. The paper concludes with a discussion of implications and limitations of these results for research and practice.

Introduction

Multi-touch mobile technology has great potential for supporting science learning (Castek & Beach, 2013). The portability of mobile technology breaks through the limitations of time and space for both teachers and learners (Traxler, 2010). With internet-connected mobile devices, students can manage their learning materials, acquire resources, and share their work online, and teachers can review students' work and give feedback or assistance almost anytime and anywhere. There are a large collection of educational applications (apps) that can support science learning (Jeng, Wu, Huang, Tan, & Yang, 2010), for example, concept mapping apps for generating a scientific model, note-taking apps for recording data and observation, and screen casting apps for demonstrating how a scientific procedure works. In addition, mobile technology allows students to remediate learning at their own pace as needed (Palloff & Pratt, 2002), such as reviewing learning resources after school.

Practitioner Notes

What is already known about this topic

- There is a growing interest in the use of mobile technology to support science education. Prior research on mobile technology in science education has mainly focused on life science in elementary schools. These studies often lacked a rigorous variance control.
- Few studies have employed a large sample size to examine how 1:1 mobile devices were used in high school physics classrooms for an extended period of time.
- The prior research did not differentiate the effect of in-class use from after-school use on physics learning performance and interest.

What this paper adds

- This study provided new insight into how high school students use mobile devices for physics learning, to what extent mobile technology disrupts traditional instructional practices, and whether students' perceived usefulness of mobile technology is consistent with their usages.
- This study added new evidence of the positive impact of mobile technology on high school students' physics learning achievement and interest.
- This study generated important evidence of the different impact of the in-class and after-school use of mobile technology on physics learning achievement and interest.

Implications for practice and/or policy

- Frequent use of mobile technology in high school physics classrooms has a positive impact on students' interest and achievement in physics.
- Mobile technology was mainly used to augment existing teaching practices, rather than to transform teaching. There is a great need to support teachers in using mobile technology to cultivate innovative practices.

A few studies have examined the use of mobile technology in science education and its impact on student learning. Ryu, Han, and Paik (2015) found that smartphones, as supplemental resources to scientific modelling activities, facilitated student collaboration and deepened conceptual discussion. In a quasi-experiment by Hwang, Wu, and Ke (2011), elementary school students used interactive concept maps on mobile devices in natural science courses that improved their attitudes towards and achievements in science learning. While these studies made valuable contributions to advancing our understanding of the role of mobile technology in science education, few studies have examined the use of mobile technology in high school physics classrooms. As shown in the latest literature review (Zydney & Warner, 2016) that analyzed 37 mobile technology studies in science education published from 2007 to 2014, only four such studies focused on physical science. Moreover, only one study involved high school students (Ahmed & Parsons, 2013). A similar observation was made by another recent review of 49 mobile technology studies in science education published since 2000 (Crompton, Burke, Gregory, & Gräbe, 2016). Only three of the studies reviewed focused on physical science, and none of the studies involved high school students. Meanwhile, few studies on mobile technology in prior research focused on tablet usages, which accounts for only 4% of the studies in Crompton *et al.* review (2016). Thanks to a larger screen size, the tablets overcome disadvantages of traditional mobile devices (Motiwalla,

2007; Siau, Ee-Peng, & Shen, 2001), and thus are believed to have greater potential for science learning (Kolk, Hartog, Beldman, & Gruppen, 2013). However, there is a lack of research focusing on tablet use in science education. Moreover, prior research mainly focused on the usage of particular apps rather than the overall usage of the multi-touch mobile device (Crompton *et al.*, 2016).

Another limitation in prior research is short duration. The duration of mobile technology use in most studies ranged from 40 minutes to 8 hours (Zydney & Warner, 2016). In particular, few studies examined the impact of mobile technology after having been used for an extended period of time in physical science. For example, the study by Ahmed and Parsons (2013), in which the authors designed an app called *ThinknLearn* to assist students in adductive inquiry investigations, appeared to have the longest duration of mobile technology use, which was about only one week. Moreover, few studies examined the relationship of effectiveness and the duration or frequency of mobile device usage in science learning. In addition, prior research on mobile technology use has mainly used case studies or small sample sizes without a rigorous statistical analysis (Crompton *et al.*, 2016; Sung, Chang, & Liu, 2016). Thus, studies with a rigorous design and a large sample size are much needed (Chen, Liu, & Hwang, 2016).

In addition, little is known about how mobile technology is used in high school physics classrooms after it is adopted. Easy access to mobile technology does not necessarily lead to frequent use in classrooms. Cuban, Kirkpatrick, and Peck (2001) reminded us that *high access but low use* is a common problem in technology integration in schools. A survey by National Centre for Educational Statistics (Gray, Thomas, & Lewis, 2010) showed that the 3000 surveyed teachers used technology only frequently for administrative tasks such as grading or attendance, and less than half of them reported frequent use in instruction. Another recent study investigated 3380 students and found low use of mobile phones for educational purposes although most students were competent to use them (Buabeng-Andoh, 2015). Common barriers to technology use include a lack of perceived usefulness of technology, absence of technical support, time pressure, limited professional training, and lack of administrative support (Arnab *et al.*, 2015; Hew & Brush, 2007). Adoption of mobile technology, despite easy access due to its portability, may also encounter the same problem. Therefore, studies about whether the mobile technology especially the tablet use will follow the same trend are necessary. Moreover, understanding to what extent mobile technology is actually used after its adoption has important implications for research and practice as many school districts have invested significant resources in adopting mobile devices (Zhang, Trussell, Tillman, & An, 2015). We also know little about whether high school students perceive mobile technology as useful for their physics learning. Perceived usefulness is a critical factor that predicts technology use (Davis, 1989). More importantly, advocates hoped that mobile technology can revolutionize science education by disrupting traditional teaching approaches and creating innovative practices uniquely enabled by mobile technology (Crompton *et al.*, 2016; Scornavacca, Huff, & Marshall, 2009). However, little is known about the extent to which mobile technology disrupts existing instructional practices in science education.

To fill in these research gaps, this study addressed the following four research questions.

- 1) How often do high school students use mobile technology in physics learning in class and after school?
- 2) How and to what extent does mobile technology change the instructional practices in physics classrooms?
- 3) How do students perceive the usefulness of mobile technology in physics learning?
- 4) How does the use of mobile technology influence students' physics learning achievement and interest?

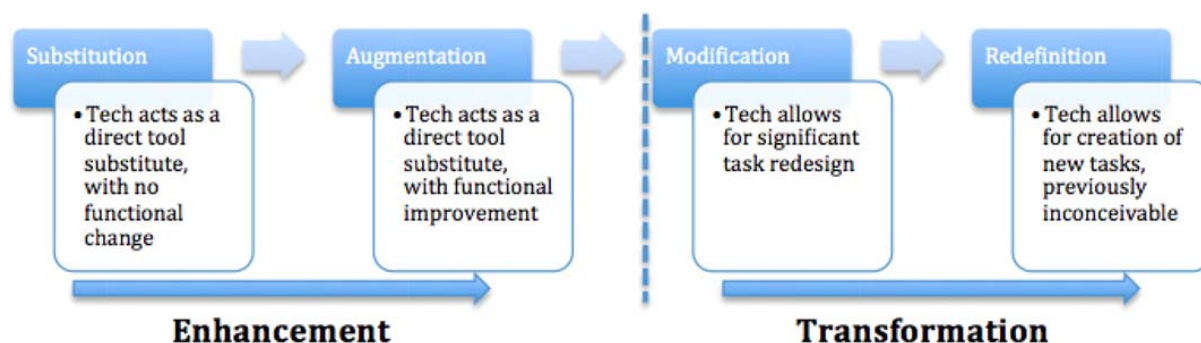


Figure 1: The SAMR model proposed by Puentedura (2006).

As the introduction of mobile technology into education, there have been different ways of using mobile technology in science learning, including use of mobile games (Avouris & Yiannoutsou, 2012), specific apps (Jeng *et al.*, 2010), or use of mobile technology to support collaborative learning (Tinker & Krajcik, 2001). These studies documented multiple benefits of mobile technology such as promoting conceptual change (Lin, Duh, Li, Wang, & Tsai, 2013), reducing cognitive load (Chiang, Yang, & Hwang, 2014), and promoting scientific skills (Marty *et al.*, 2013). However, few studies analyzed the extent to which the mobile devices support the science learning or change the instructional practice.

To examine how mobile technology disrupts traditional instructional practice, we employed the SAMR model by Puentedura (2006) which conceptualized the implementation of technology in learning as four levels of progression: substitution, augmentation, modification and redefinition (see Figure 1). The substitution and augmentation levels are regarded as enhancement of existing instructional practices, while modification and redefinition are regarded as transformation of instructional practices. The SAMR model has been used to study technology use in many fields such as higher education and biology education (Romrell, Kidder, & Wood, 2014), but it has not been used to study the levels of mobile technology integration in physics education.

Method

Context

This study took place in a high school in a medium-sized city in eastern China. Inspired by the potential of mobile technology, the school administrators launched a 1:1 technological initiative in 2014. Financial support was provided to ensure that each student owned a tablet and was able to access resources from a regional network. To organize the learning resources and make them affordable to teachers and students, researchers, teachers, and local technology vendors collaborated to develop a formal mobile learning environment. An e-cloud platform was developed to store all the learning resources, which could be accessed by teachers and students in classroom and after school. An interactive learning management system was developed and installed on the mobile devices of both teachers and students and was used in daily instruction. With the learning management system, students could communicate with teachers or peers to display their ideas and teachers could supervise, scaffold and evaluate students. The system included various functions to support students' usages of the tablets such as resource management, the online assistant, and instructional preparation on the teacher tablets (see Figure 2). The mobile devices were connected to an interactive whiteboard in the classroom. The interactive whiteboard was used by teachers to organize the class with students, and the teacher tablets were used to interact with the students after school.

To help teachers use the tablets in teaching, the high school provided multiple sessions of professional training. First, the teachers in the computer science department and the lead teachers in

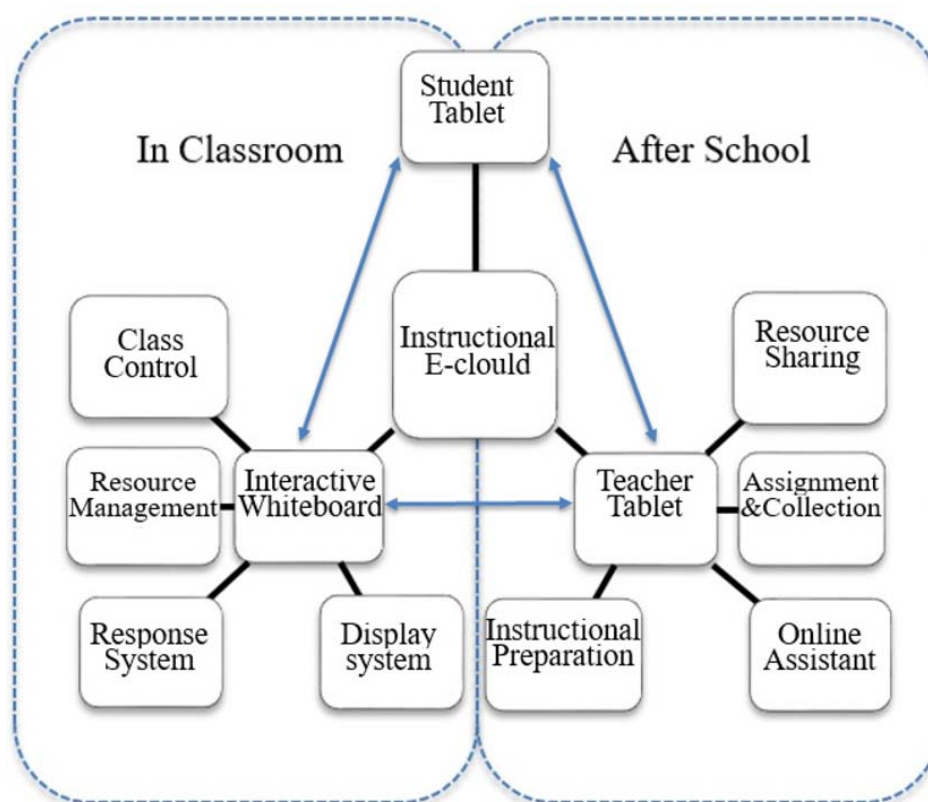


Figure 2: The Supportive Functions of the Interactive Learning System.

each subject area formed a steering group. This group collaborated with researchers and local technology vendors to implement the learning system and produce a manual document for other teachers. Members in the steering group also visited other schools that had experience of mobile learning to learn pedagogical knowledge. Second, the steering group offered professional development workshops to other teachers in the school. The lead teachers also demonstrated the use of mobile technology in their classes to other teachers. Therefore, all teachers were prepared to use the mobile devices and the learning system in their own classroom. Finally, the teachers trained their students to use the devices.

Participants

The participants in this study were 831 high school freshmen (428 males and 403 females) in 28 classrooms. Their age ranged from 14 to 16 years, while most were 15 years old. Each student had a tablet with the learning management system installed. Students were allowed to take their tablets home, so they could use it for study after school.

Mobile technology survey

In order to investigate how the students used the mobile devices for learning physics, we collaborated with the teachers to develop a questionnaire to examine the frequency and duration of use, as well as a descriptive protocol of the specific usage, both in class and after school. First, we reviewed the manual documents that the teachers received for supporting their mobile technology use. We then interviewed the lead teacher in the physics department in the high school and gathered input from other physics teachers about the types of mobile technology usage in their classrooms. We developed a pilot survey based on the teachers' input and the manual documents and tested the survey with 23 high school freshmen. We solicited students' responses on additional ways of using mobile technology by open-ended questions that were not covered in the survey. We revised the pilot survey to a questionnaire and a descriptive protocol based on

students' input, and then solicited teachers' input. The final descriptive protocol used to compare the mobile technology-supported instruction and conventional instruction was provided in Table 2, and the questionnaire contained two components.

Frequency and duration of mobile technology use

The final survey included 24 items on a 5-point Likert-scale (4 items for the overall frequency and duration of use and 20 items for the frequency of use of specific functions). The Cronbach's coefficient was .739 for the four overall items and .952 for the 20 specific items.

Perceived usefulness of mobile technology

To understand students' perceived usefulness of mobile technology, we developed 17 items for the most frequently used functions of the mobile devices. The 17 items shared the same 5-point Likert-scale with five representing "very effective" and one representing "not effective at all." The Cronbach's coefficient of the items was .954.

Interest in physics learning survey

We also investigated the effect of mobile technology on students' interest in physics learning. The interest items were revised from Lamb's study (2012). We selected and revised four items that shared the same 5-point Likert-scale. An example is "Compared to pursuing test scores, I prefer to enjoying the inquiry process of learning physics." The Cronbach's coefficient for these items was .849.

Achievement tests

To determine students' initial performance in physics learning, we employed students' scores in their entry physics test, which was administrated immediately after they entered the high school to decide student placement based on their levels. The students took another physics test at the end of the semester, which was a summative assessment administered by the school district. Student performance on this end-of-semester test was used as the indicator of student achievement of the physics learning after the mobile technology was introduced.

Data analysis

To determine the levels of different ways that mobile technology was used in physics classrooms, the first author (a veteran physics educator) and the second author (an experienced educational technology researcher) coded the specific usages in the descriptive protocol together and reached agreement on the level of each usage according to the SAMR model.

For the survey, we first examined students' responses to remove invalid data. We excluded the samples in which 95% of their responses to all of the items were either 1 or 5, which indicated that the students either had a strong bias towards mobile learning or perhaps mindlessly responded to the survey to simply get it done. After excluding these invalid responses, 803 student responses (409 male and 394 female) were used in the final analysis.

To examine the effect of mobile technology on students' physics learning, it is necessary to control other confounding variables, such as teacher effect, peer effect and class context effect due to the fact that the students came from 28 classrooms. Therefore, we employed a fixed-effects model to control those undetected variances (Borenstein, Hedges, Higgins, & Rothstein, 2010). We also controlled the covariance of students' gender and initial physics achievement when they entered high school in our model. The model was formulated as follows:

$$Y_{sc} = \beta_0 + \beta_1 \text{Gender}_{sc} + \beta_2 \text{Prescore}_{sc} + \beta_3 \text{Treatment}_{sc} + \mu_{sc} + \varepsilon_{sc}$$

In the model, Y_{sc} is student s 's outcome (physics interest or physics score) who settled in class c ; Gender_{sc} represents his/her gender; Prescore_{sc} represents his/her score in the entry physics test; Treatment_{sc} is the frequency or duration of use of mobile technology by student s . In this analysis, we separated the treatments into the in-class and after-school treatment. μ_{sc} represents the class fixed effect, and ε_{sc} is the error term.

Table 1: Frequency and duration of mobile technology use

Frequency				Duration			
In class	%	After school	%	In class	%	After school	%
Used in most classes	79.70	≥3 times per week	84.18	>30 minutes	32.75	>30 minutes	17.68
Used in about half classes	9.46	2-3 times a week	9.34	>15 minutes	79.95	>15 minutes	71.11
Used in less than half classes	7.35	Once a week	4.36	>5 minutes	94.65	>5 minutes	92.90
Seldom used	3.36	Less than once a week	2.12	≤5 minutes	5.35	≤5 minutes	7.10

Results

Frequency of mobile technology use in physics learning: high access and frequent use

Overall frequency and duration of mobile technology use

The students used the mobile devices very frequently both in class and after school for physics learning (see Table 1). Specifically, 79.70% of students reported that they used mobile devices in most classes (more than half of their classes each week), and 84.18% of students reported that they used it more than three times per week after class (they had physics classes on three days per week).

The results also showed a long duration of use both in class and after school (see Table 1). Specifically, 32.75% of students reported that they used mobile technology for more than 30 minutes per class on average, which is equivalent to 67% or more of a typical physics class period (45 minutes), and overall 79.95% reported a duration of more than 15 minutes of a physics class period. In addition, 17.68% of students reported that they used mobile technology for more than 30 minutes for physics learning after class per day and, overall, 71.11% of students reported that they used it for more than 15 minutes per day for physics learning after class. In other words, the majority of the students reported using their tablets to learn physics on their own for at least 15 minutes a day, either in class or after school.

Frequency of using specific functions in class and after school

All of the 20 specific functions of mobile technology were highly frequently used by nearly or more than 30% of students according to the survey (see Figure 3). The two most frequent uses in class were *Screen broadcast* (88.04%) and *Use learning guide* (60.52%), both of which were teacher-driven usages. The two least frequent uses in class were *Discussion aid* (24.41%) and *Use incorrect item set* (24.41%). The two most frequent uses after school were *My homework* (77.46%) and *Review learning guide* (58.03%). The two least frequent uses after school were *Class note* (22.17%) and *Mindmap* (18.68%).

The analysis showed that the average frequencies of in-class usage and after-school usage for the specific functions were significantly correlated $r(801) = .789, p < .001$ (see Figure 4).

How mobile technology changed instructional practice in physics classroom

The survey results showed that all of the specific usages were intended to enhance physics instruction, rather than to transform the instructional practices in physics classrooms (see Table 2). Among the 20 specific usages in class and after school, most aimed to augment physics instruction. Only three usages, *Picture loading*, *Discussion aid* and *My textbook*, were considered direct substitution of conventional instructional activities. There was no use aiming at modification or redefinition of physics instruction.

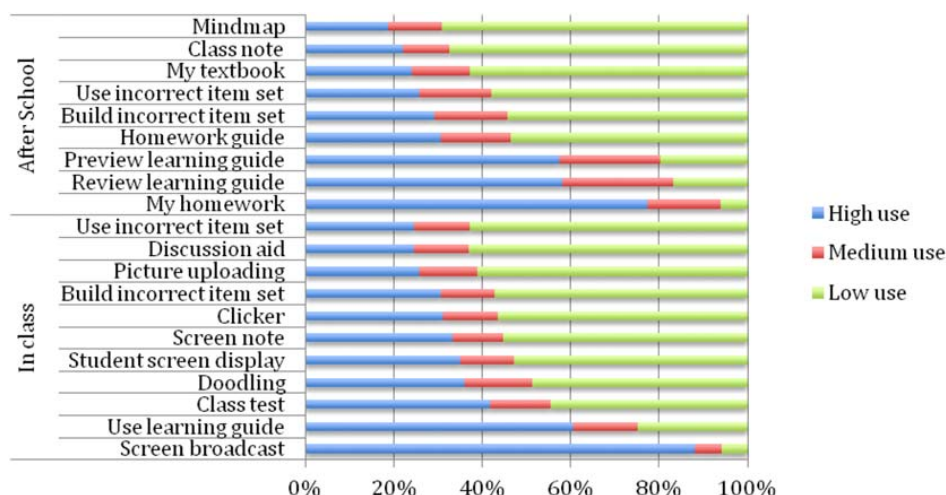


Figure 3: Percentage of frequency for specific usage in terms of low, medium and high use.

*The frequency was calculated by the average rating (m) of items on the 5-point Likert-scale: High use: $5 > m \geq 3$, medium use: $3 > m \geq 2$, low use: $m < 2$. High, medium and low uses in class refer to used in more than half of the classes, used in less than half of the classes, and seldom used in classes, respectively; for after school use they refer to more than 2-3 times a week, once a week, and less than once a week, respectively.

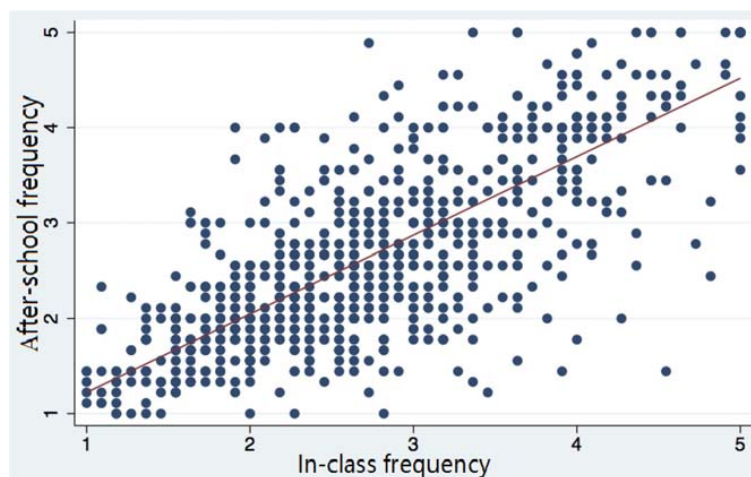


Figure 4: The relationship of in-class use and after-school use in terms of frequency.

The in-class usages of mobile technology enhanced instruction in three ways: direct lecture, interaction between teacher and student, and immediate feedback on student performance. In conventional physics classes, teachers lectured while students watched the blackboard, listened and took notes at the same time, which may distract students due to time pressure. Some students at the back of a large classroom (typically with more than 40 students) might have difficulty seeing the detail on the blackboard. Mobile technology improved the situation by offering quick note taking and easy visualization (eg, screen broadcast). The mobile technology also enhanced the teacher-student interaction. For example, after a physics experiment, the teacher asked students to upload the results. He could review all the students' work and then select the typical ones to display on the whiteboard. This process was more efficient than what happened in a conventional large classroom. Moreover, mobile technology provided immediate feedback to teachers. Teachers could get statistical analysis of student performance immediately after asking

Table 2: Functions, specific usages of both mobile supported and conventional instruction, and the SAMR coding levels

Function		Mobile technology-supported instruction	Conventional instruction	SAMR model
In class	Screen broadcast	Students watch slides or other material offered by teachers from mobile-device screens. They can take screenshots and store the content in their own files.	Students watched blackboard directly, some students who sat in the back of the classroom had difficulty seeing the content clearly. They had difficulty taking notes due to time limitation.	A
	Screen note	During teachers' lectures or discussion between peers, students take notes about ideas or critical arguments on the device, and store or share with others.	Students took notes on paper. Most students did not have sufficient time to write down every important points.	A
	Picture uploading	When teachers assign subjective work to students, they can upload pictures of their work, test, or drawing immediately during class.	Students submitted assignments to teachers by paper. If teachers wanted to show a student's work to everybody, he/she needed to ask the student to share their work on the blackboard.	S
	Doodling	When teachers broadcast screens or assign subjective work, students can write or draw directly on the screen and store or submit to teachers.	Teachers usually showed the task on the blackboard, and students copied and completed the task on their written notes.	A
	Clicker	When teachers have formative questions, quick tests, or votes for students to monitor or adjust the instruction, they will ask students to respond by using clickers.	Teachers asked students to raise hands for voting or asked individual students to respond. Some shy students might not raise hands and thus it was hard for teachers to collect assessment information from every student.	A
	Class test	When teachers want to monitor students' learning outcome during class or at the end of class, they will assign a class test to students. Teachers can retrieve statistics of test results immediately.	When teachers administered tests on paper or displayed the tasks on the blackboard, it is difficult for them to obtain any statistics of student responses immediately, and the conventional technic cannot provide on-the-fly feedback to teachers to inform teaching.	A
	Screen display	Teachers display a student's screen to the whiteboard to show the student's work or drawing. Students can explain their work at the same time.	Teachers asked a student to verbally explain his/her work. Other students may not be able to visualize their work.	A

Table 2: Continued

	Function	Mobile technology-supported instruction	Conventional instruction	SAMR model
	Discussion aid	Discussion and communication according to the resources, work, or drawing in the device. Students can share work with peers.	Students discussed questions based on their written notes.	S
	Use learning guide	Students can watch the guide resources (pictures, videos, simulation experiments, etc.) that accompany the teacher's explanation. Teachers can check the statistical report and adjust their instruction.	Students revisited the textbook if they had questions. The learning guide resources were limited.	A
	Build incorrect item set	Students add items to the incorrect item set and insert tags or notes.	Students selected and marked the items they made mistakes, and then copied them into the incorrect item set after class. Most did not have enough time for this.	A
	Use incorrect item set	Review or management of incorrect item set in the device, such as highlighting, marking, searching, indexing, etc.	Students reviewed the paper version of the incorrect item set. It is not convenient to reorganize and search a specific type of errors or item.	A
After school	Preview learning guide	Use of resources in learning guide (texts, pictures, videos, simulation experiments, etc., provided by teachers for class usage) to prepare for class.	Students used other sources such as textbooks, guide books, etc. as a preview. The sources are rare.	A
	Review learning guide	Use of resources in learning guide (texts, pictures, videos, simulation experiments, etc.) to review the learned content.	Students reviewed content according to written notes. They did not have the opportunity to review the sources used in class.	A
	My homework	If the homework consists of objective multiple-choice items, statistics of student answers can be summarized and reported to teachers automatically. If the homework consists of subjective items, students can complete them on paper and upload them by taking pictures. Teachers correct or give comments on them directly.	Students submitted their homework by paper. It was time-consuming for teachers to review and provide feedback to all the homework. Teachers had to spend additional time to summarize the patterns of students' responses.	A

Table 2: Continued

<i>Function</i>	<i>Mobile technology-supported instruction</i>	<i>Conventional instruction</i>	<i>SAMR model</i>
Homework guide	Students use this during or after homework as it can provide guides such as micro-videos or electronic resources organized by teachers.	Students had to check other resources like the textbooks to gain assistance. These resources were not as effective as the micro-videos, etc.	A
My textbook	Students read and search through the e-version of the textbook. It is easy to insert tags, highlight, etc.	Students used paper versions of textbooks, which are heavy to carry and non-searchable.	S
Mindmap	Students use this function to build knowledge structure or concept maps when taking notes or summarizing what they have ended especially at the end of a chapter.	Students used written notes to construct knowledge structures/map, which is less convenient compared to Mindmap.	A
Class note	Students review class notes after class, which can be easily modified, reorganized, tagged, and searched, etc.	Students reviewed written notes, but they are not easy to reorganize or search.	A
Build incorrect item set	Students add items to the incorrect item set and add tags or notes.	Students copied items into the incorrect item set, which was time-consuming.	A
Use incorrect item set	Students review, organize, or manage the incorrect item set in the device, such as highlighting, marking, searching, indexing, etc.	Students reviewed the paper version of the incorrect item set, which was not convenient to reorganize and search the items.	A

Note. S = Substitution; A = Augmentation; M = Modification; R = Redefinition.

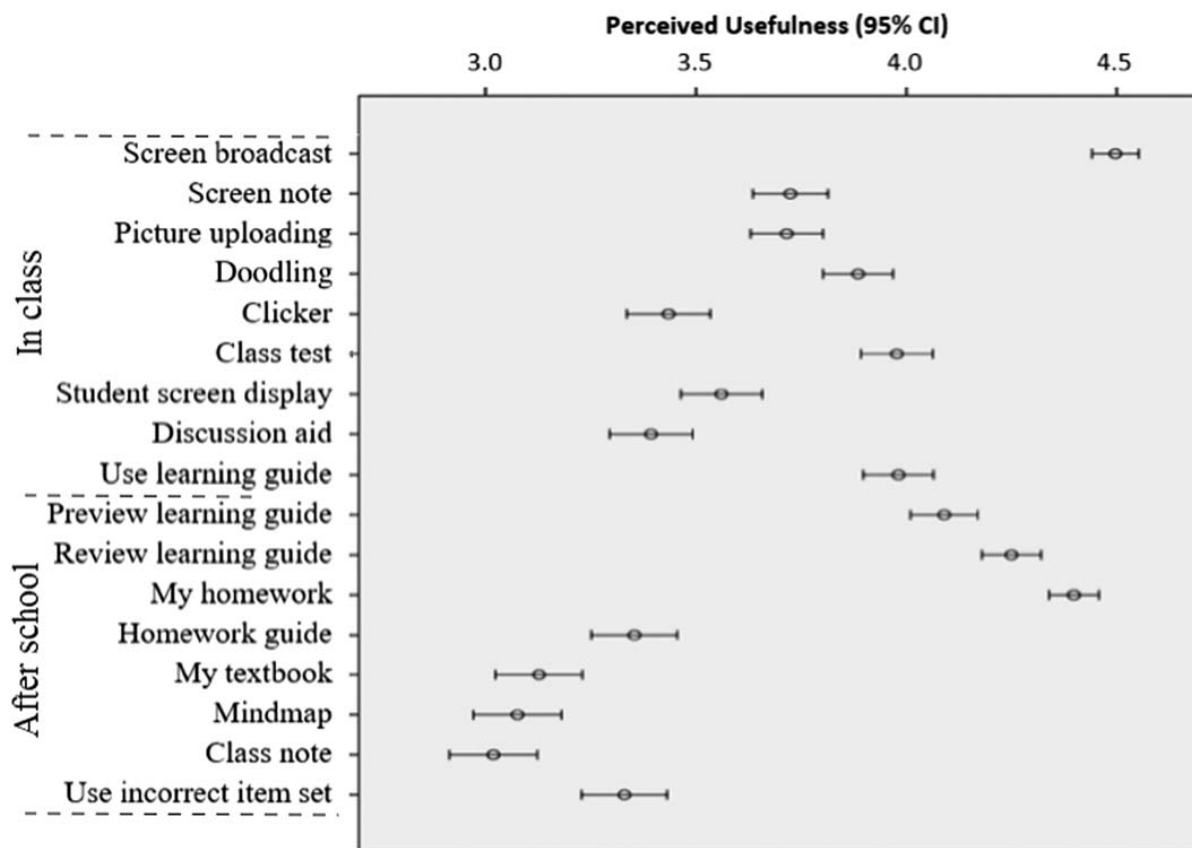


Figure 5: Perceived usefulness of mobile technology by students.

the class a question or administering a quick quiz. The formative assessment helped teachers determine next instructional moves and adjust the pace of the moves.

The mobile technology also offered support for students' self-study after school. First, students could access additional online resources to strengthen their classroom learning. For example, they could review the video of the physics experiment uploaded by teachers for remediation. Second, the homework was more manageable for both students and teachers. Students could get aids by using homework guide, while teachers could obtain results of student performance immediately and comment on student work. Additionally, mobile technology made it easier to manage the learning resources for students. For instance, it was time-consuming to add, remove, categorize or search incorrect items in the past, but the mobile technology made it more convenient and efficient for students.

Perceived usefulness of mobile technology in physics learning

The average perceived usefulness rating of all the mobile technology functions was higher than 3.0 with a 95% confidence interval on a 5-point Likert-scale (see Figure 5). The two most useful functions perceived by the students were *Screen broadcast* (4.50) and *My homework* (4.35), which were also the two most frequently used functions.

To determine whether the perceived usefulness rating was consistent with the frequency of use, we examined the correlation of the perceived usefulness rating with in-class and after-school usage frequency, respectively. The results indicated a high correlation with both in-class ($r(801) = .690, p < .001$) and after-school use ($r(801) = .682, p < .001$) (see Figure 6).

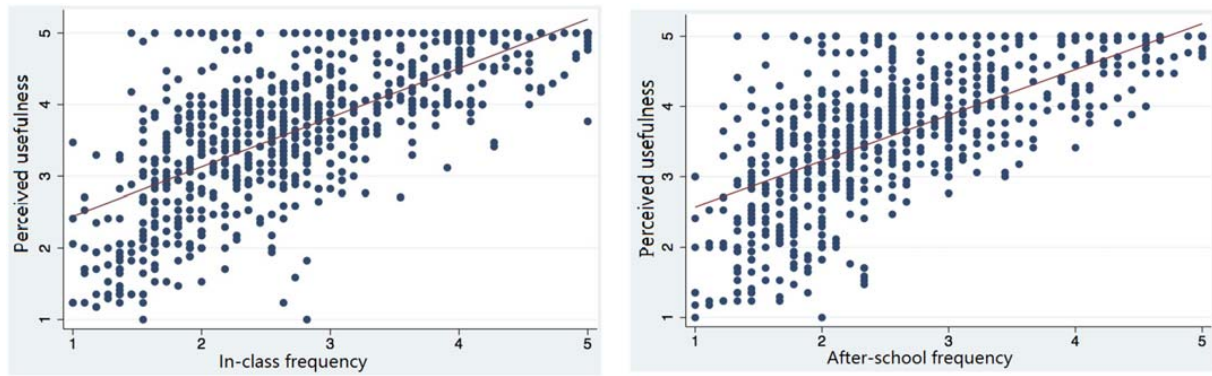


Figure 6: The relationships of perceived usefulness and using frequency.

Table 3: Physics learning interest and achievement by using frequency and time effect

	Using frequency effect (coefficient)		Using time effect (coefficient)	
	In-class r (p -value)	After-school r (p -value)	In-class effect r (p -value)	After-school effect r (p -value)
Interest in physics learning	.082**(.001)	.113***(.000)	.111***(.000)	.114***(.000)
Achievement	3.715***(.000)	1.055*(.037)	2.184***(.000)	3.138***(.000)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Mobile technology: promoting physics learning interest and achievement

To confirm that the students are random distributed at different levels of frequencies and durations, we conducted correlation analysis between the in class/after school frequency or duration of mobile usages and their pre-score. Results indicated a very slight correlation, and the largest correlation coefficient is between the pre-score and the in-class frequency as $r(803) = .146$, $p < .01$. The observed statistical significance is mostly due to the large sample size used in this study. Thus, we rule out the possible relationship between students' prior physics learning and their reported frequencies and durations of using mobile technology.

We found strongly significant effects of frequency and duration of mobile technology use on students' physics learning interest and achievement after controlling students' gender and pre-scores (see Table 3). The effect of in-class frequency of use ($r = .082$, $p < .001$) on physics learning interest was weaker than the after-school effect ($r = .113$, $p < .001$), while the duration effect was similar for both in-class effect ($r = .111$, $p < .001$) and after-school effect ($r = .114$, $p < .001$). For students' physics learning achievement, we found a stronger effect of in-class frequency of use ($r = 3.715$, $p < .001$) on students' achievement than after-school frequency of use ($r = 1.055$, $p < .05$), while the effect of in-class duration of use ($r = 2.184$, $p < .001$) was lower than the after-school effect ($r = 3.138$, $p < .001$).

Discussion and conclusion

This study contributed to the mobile technology research in science education in the following four ways. First, prior studies suggested that high access to technology does not necessarily mean that students will often use it (Cuban *et al.*, 2001), but our study found that the mobile devices were frequently used in physics classroom. Gurung and Rutledge (2014) warned us that we should not be "overly enthusiastic or pessimistic about the digital learners for mobile learning (p. 99)." There are many obstacles for mobile technology usage in classroom. For example, recent

studies noted that teachers' negative beliefs about mobile technology might be one of the major factors that prevent teachers from using mobile learning in science classroom (Ifenthaler & Schweinbenz, 2013; So, Choi, & Yoon, 2015). However, teachers in our study did not hold negative beliefs about mobile technology, perhaps thanks to the accessibility, portability and affordance of the devices and the learning management system. The system and iCloud platform provided convenient access to learning resources in class and after school. For example, teachers could assign homework through *My Homework*, which students could complete with the *Homework Guide*, and then submit the homework online. Teachers could easily review the statistics of student homework provided by the system and provide feedback directly. They could also adjust subsequent lessons based on student performance. The efficiency and convenience of these features might be the reasons for the frequent use of mobile technology by both teachers and students in our study. In addition, the professional development training that the teachers received for using mobile technology and the on-going administrative support seemed important for the frequent use (Arnab *et al.*, 2015; Hew & Brush, 2007).

Moreover, we found strong correlation between students' in-class use and after-school use of mobile technology. This level of consistency might also be a factor to promote the frequent usage. In contrast to prior studies that found disconnection between in and out of school usage of technology (Clark, Logan, Luckin, Mee, & Oliver, 2009; Wang, Hsu, Campbell, Coster, & Longhurst, 2014), this study suggested that, with appropriate professional training and support, mobile technology can be frequently used both in and outside of science classrooms. This is an encouraging finding given the typical *high access but low use* problem in educational technology.

Second, we found that mobile technology mainly augmented instructional practice in the physics classroom, rather than transforming it, despite its frequent use and the positive outcome. This result is consistent with the prior study (Peled, Blau, & Grinberg, 2015). Nonetheless, these usages enhanced the conventional physics instruction by improving learning in five ways: (1) time saving (eg, Screen note); (2) extending perception (eg, Screen display); (3) ease of accessing and managing resource (eg, Homework guide); (4) timely feedback (eg, Clicker); and (5) remediating learning (eg, Review learning guide). We speculated two reasons why the usages of mobile technology were limited to only augmentation to conventional instruction. First, the usages have not been adequately facilitated students' role as active learners. We found that the most frequent use was teacher-driven and the least frequent use was student-driven. Learning activities that engage students in a more interactive and engaging matter need to be designed and implemented by teachers. This claim is consistent with the study conducted by (Reychav & Wu, 2015). Second, the usages reported in this study are too broad to address the disciplinary design principles in physics learning. This aligns with the warning by Romrell *et al.* (2014) that to transform learning, there should be personalized, situated and connected design of integration between mobile technology and the specific learning activities. In summary, our findings imply that there is a great need for integrating mobile technology with physics learning activities on the part of users or instructors to promote innovative practices in physics instruction uniquely enabled by mobile technology.

Third, this study found that students perceived mobile technology as highly useful for physics learning and their perception were highly correlated with the frequency of use. This finding adds literature with the high-perceived usefulness of mobile technology (Bebell & O'Dwyer, 2010; Penuel, 2006; Scornavacca *et al.* 2009; Wilson, 2014). Additionally, in alignment with Davis (1989), this finding also provides new evidence to support the argument that perceived usefulness is a potential internal factor that influences the use of mobile technology.

Finally, with more rigorous quantitative methods to control the covariance, the results gave us more confidence to claim that both duration and frequency of mobile technology are correlated

with students' physics learning interest and achievement. This finding is partially consistent with a previous study in which authors found that duration of using tablets in the Smart classroom was only correlated with the achievement and interest for high performing students (Zhai, Sun, Guo, & Zhang, 2016). The in-class and after-school duration of use effects are both significant predictors of students' physics learning interest and achievement, as is the case with the in-class and after-school frequency of use effects. These positive achievement results are consistent with previous findings in physics learning by Ahmed and Parsons (2013) in which they examined the efficacy of one specific app in physics learning.

We also note some limitations of this study. First, we did not obtain data about the teachers' perceived usefulness. Future studies should examine the perspectives of teachers, which may contribute to the transformation of the instructional practice (Ifenthaler & Schweinbenz, 2013). Second, the fixed-effects model that we used to examine the effect of mobile technology on students' physics learning could be enhanced by including students' initial interest level in physics learning as a covariate. Third, this study examined the usefulness of mobile technology use overall, without looking into the effectiveness of each specific usage, which would be a fruitful research area for future studies. Finally, although we found positive results for students' physics achievement and interest, this does not mean that the effects of mobile learning on students with different achievement levels are similar. Future work should also explore the differences among diverse groups.

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Statements on ethics, open data and conflict of interest

The data can be accessed by contacting the first author. There were no ethical issues related to the selection and treatment of subjects associated with this paper. The authors had no conflicts of interest in conducting and supporting this study.

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